# BEHAVIOR OF PARTIALLY-PRESTRESSED CONCRETE EXTERIOR BEAM-COLUMN JOINTS FOR HIGHLY-SEISMIC ZONES

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***Abstract***

The high intensity and frequency of earthquakes occurred in the past two decades has brought a deep trauma to the Indonesian people, particularly those who live in the highly seismic regions. According to the latest building codes including the Indonesian building standards, a multistory or high-rise building should be designed to have a ductile manner during the severe earthquake strikes. The structural components such as beam-column joints as parts of a frame system must be sound and ductile so that the building will withstand a moderate or even severe earthquake. The research conducted here is to study the ductile behavior of monolithic joints of a ductile frame system with partially prestressed concrete beams and reinforced concrete columns under cyclic loading to simulate the earthquake. As the results, the ratio of the yielding load capacity to the designed/ideal load in accordance with the Indonesian seismic code (SNI 03-1726-2002) at story drift of 3.50 percent is about 1.23, which is larger than 1.20 as required by the design code. Three criteria of structural stability as per ACI-374.1-05, i.e. (1) the ratio of the test capacity to the designed capacity of the specimen at story drift of 3.50 percent, which is found as 74.22 percent under pushing lateral loading, which is slightly lower than 75.0 percent as required, whereas under pulling lateral loading it could reach up to 87.0 percent which is higher than the requirement; (2) the dissipation energy ratio ($\beta$), at drift ratio of 3.50 percent, it could reach up to 0.91 which is larger than 0.75 as required; (3) the ratio of hysteretic loop gradient, which is limited by the abscissa X from –X and +X, at drift ratio of 3.50 percent, is about 0.04 which is larger than 0.05 under pushing lateral loading and it is about 0.054 which is also larger than 0.05 under pulling lateral loading; The structural ductility, $\mu$, at drift ratio of 3.50 percent is greater than 4.0. According to the requirements of both NEHRP and ACI, a building structure with load capacity higher than 75 percent of the maximum load capacity at story drift of 3.50 percent, has been considered to satisfy the requirements for ductile structures.

*Keywords*: *Beam-column joint*; *Concrete*; *Cyclic loading*; *Ductility*; *Earthquake*.

## 1. INTRODUCTION

For decades, reinforced concrete has been used as structural members for many construction purposes.[1-20] However, the use of prestressed concrete in seismic resistant structures has been increasing popular in recent years. Just like any other new material, it will attract criticism and comment, sometimes by people who may not have had the opportunity of full investigation of the material in question. Furthermore, today engineers are more critical of any new material or technique and will seldom accept them unless conclusive evidence of their performance can be produced. This is as it should be.

The research reported here concentrates on the tests of exterior beam-column joint sub-assemblage specimens of a multistory building, which was designed to perform in a ductile manner during the earthquake loading.[21-23] The beam-column joint specimens were the assembly of reinforced concrete columns and partially prestressed concrete beams. These members were assembled monolithically without special concerns on the design of plastic hinge formation.[24-25]

Partially prestressed concrete beams were normally used in the multistory buildings, in which they have long spans between columns, and functionally or aesthetically required to have shallower beams. These partially prestressed beams are suitable to be implemented in the seismic-loading dominated multistory buildings rather than the traditional full prestressing system which is normally applied for the bridges. In the application of full prestressing system, the prestressing tendon is considered to fully work without taking into account the contribution of mild reinforcing steel in resisting the load. In such analytical computation, the reinforcing steel is considered as practically provided such that the design of a structure will be uneconomical since the contribution of the reinforcing steel in resisting the flexural load is neglected.[26-31]

## 2. RESEARCH SIGNIFICANCE

The research is conducted to study the actual capacity and ductility of the exterior partially-prestressed concrete beam-reinforced concrete column joint under lateral cyclic loading to simulate the actual seismic loading. It is expected that the prestressing tendon works together with the mild steel in resisting the flexural and lateral loads. The authors wish that the study could come up with a more economical and better performance of prestressing system rather than using a traditional full prestressing or partially prestressing system, but disregarding the contribution of mild steel in resisting the seismic load, particularly for buildings that require long spans.

## 3. EXTERIOR BEAM-COLUMN JOINT

A full scale experimental test was conducted on an exterior prestressed concrete beam-reinforced concrete column joint as can be seen in Figs. 1 to 5.

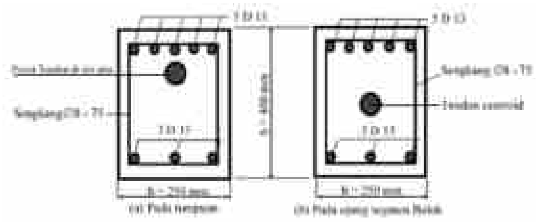

Fig. 1 Partially-prestressed concrete beam section

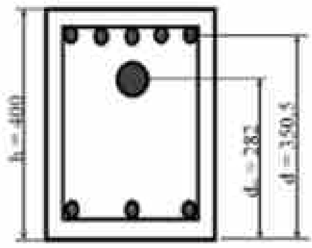

Fig. 2 Effective depth of prestressed concrete beam

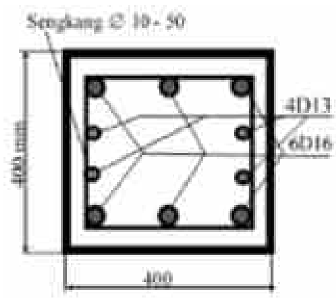


Fig. 3 Reinforced concrete column section

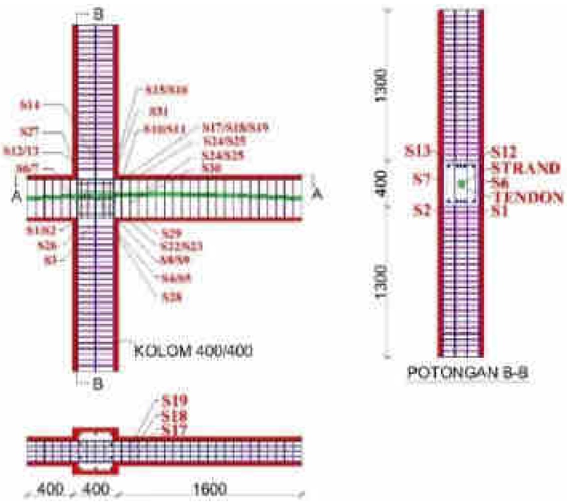


Fig. 4 Exterior joint specimen

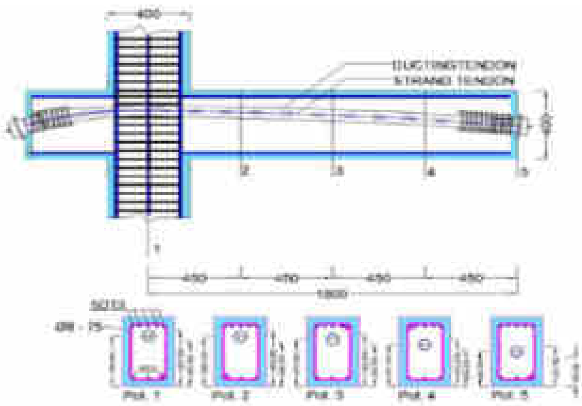

Fig. 5 Eccentricity of the prestressing tendon

## 4. LOADING APPLICATION

The lateral load was cyclically applied to the exterior beam-column joint through an 1000 kN actuator. The intensity of the lateral load was measured using load cell under different drift ratio, starting from 1.00 up to the maximum drift ratio required by the standard, i.e. 3.50 percent. However, during the test, it was continued in excess of that value to show the performance of the joint under higher drift ratio that is up to 4.50 percent, even though the NEHRP and ACI only require the maximum drift ratio of 3.50 percent and it is deemed sufficient to examine the ductility demand of a structure. The axial static load for the column was designed to be constant as about 10.0 percent of the column capacity, i.e. 10 percent of 6400 kN (640 kN).

## 5. ANALYTICAL APPROACH

### 5.1 Load capacity

The designed/ideal load $P_i$ is smaller than the yielding load $P_y$ from the experimental test. The ratio of $P_y/P_i$ equals to $f_i$, where $f_i$ is governed by SNI 03-1726-2002. The minimum requirement is 1.20.

### 5.2 Structural stability

To ensure the stability of a structure, there are three stability criteria as follows:
(1) at the end of the test, the lateral load should not be less than 75 percent of the maximum load in the loading direction;
(2) the relative energy dissipation ratio ($\beta$): ratio of parallelogram area formed by the intersection of hysteretic loop end at certain story drift and the stiffness at corresponding story drift should be greater than 0.125.
(3) the hysteretic loop gradient ratio, which is limited between –X and +X should be greater than 0.5 times the onset gradient of a structure at first loading cycle.

## 6. TEST SETUP

The test of exterior concrete beam-column joint was arranged such away so that the axial loading could be maintained vertically during all stages of the lateral loading application. The setup is illustrated in Fig. 6.

Fig. 6 Test setup of the joint specimen

## 6. RESULTS AND DISCUSSION

The hysteretic data of the test specimen was obtained by using the linear variable displacement transducer (LVDT), strain gage (SG), and wire gage (WG). The corresponding data is for developing the relationships of the curves as follows:
(1) Hysteretic loop obtained from LVDT measurement is the relationship between lateral load $V$ and lateral deflection at the top of the column as shown in Fig. 7.

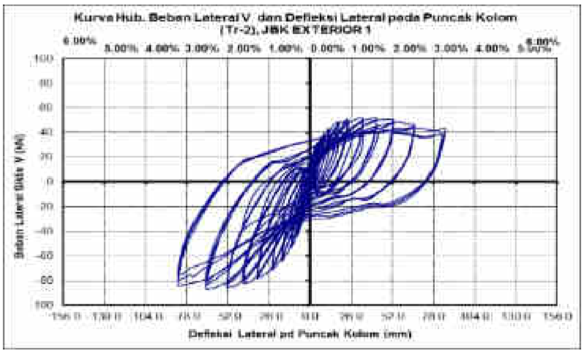


Fig. 7 Hysteretic loop obtained from LVDT measurement at the top of the column

(2) Hysteretic loops obtained from strain gage (SG) measurements, as can be seen Fig. 8, are the relationships between lateral load $V$ and lateral deflection, which are represented by SG-13 and SG-27;

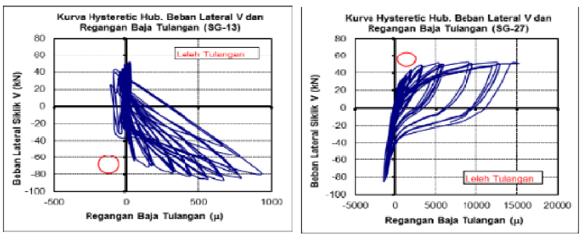


Fig. 8 Hysteretic loops obtained from SG-13 and SG-27 measurements

(3) Hysteretic loop obtained from wire gage (WG) measurement as shown in Fig. 9, which was installed only at one location, i.e. at the top of the column, since the maximum lateral displacement occurred at the top of the column or at the level of the application of cyclic lateral loading by using a horizontal actuator.

## 7. TEST RESULTS

The data is used to compute the ratio of the load capacity as well as the structural stability based on the applied load.

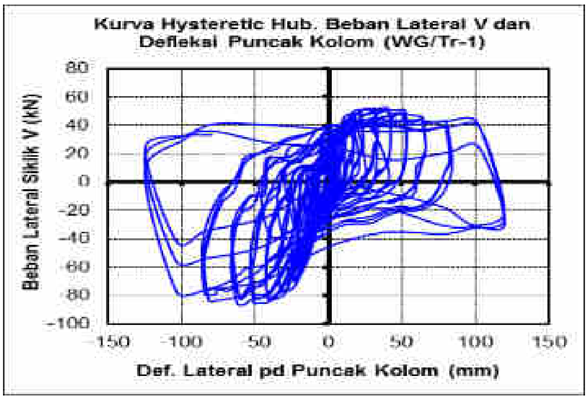


Fig. 9 Hysteretic loop obtained from WG at the top of the column

### 7.1 Ratio of yielding load capacity to designed load capacity

At drift ratio of 3.50 percent, the value of $P_y$/Pi should be greater than $f_i$, where $f_i$ equals to 1.20. $P_y/P_i$ = 123.98/101.0 = 1.23 $\geq$ 1.20.

### 7.2 Structural stability

There are three criteria in accordance with ACI-374.1-05, which should be satisfied as follows (Fig. 10):

(1) at third cycle and a drift ratio of 3.50 percent (limited to this value), from Fig. 10, the test pushing load is 38.30 kN and the maximum pushing load is 51.60 kN. The ratio is 38.30/51.60 = 74.22 percent < 75.0 percent (slightly greater). For pulling load, the ratio is 74.80/86.00 = 87.00 percent > 75.0 percent;

(2) at third cycle and a drift ratio of 3.50 percent, from Fig. 11, the relative energy dissipation ratio ($\beta$) is as follows:

$A_n$ = 9341.50 kNm

$(E_1 + E_2) + (\theta'_1 + \theta'_2)$ = 10298.93 kNm

$\frac{An}{(E_1+E_2)+(\theta'_1+\theta'_2)} = \frac{9341,50}{10298,93} = 0,91 > 0,125$

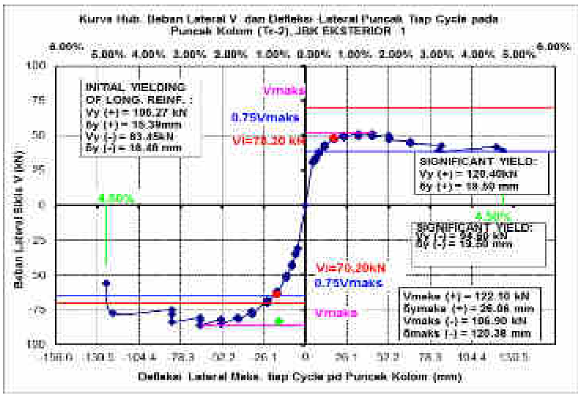


Fig. 10 Relationship between lateral load $V$ and lateral deflection at each cycle back bone at the top of the column (Tr-2)

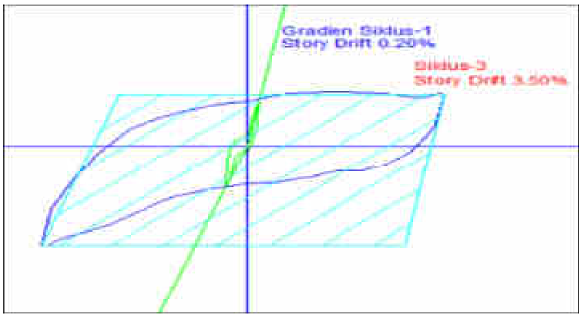


Fig. 11 Energy dissipation curve area at the third cycle and a story drift of 3.50 percent and the parallelogram area with a gradient of 0.20 percent

(3) at third cycle and a drift ratio of 3.50 percent, the hysteretic loop gradient ratio which is limited by the abscissa X from –X to +X is as follows (see Fig. 11):

- under pushing load, the ratio of hysteretic loop gradient at the third cycle and a story drift of 3.50 percent to hysteretic loop gradient at the first cycle and a story drift of 0.02 percent = tan 14.37/tan 73.49 = 0.04 < 0.05 (slightly lower).

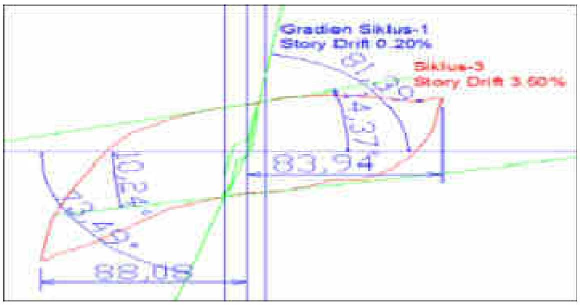


Fig. 12 Curve gradient ration at the third cycle and a story drift of 3.50 percent

- under pulling load: the ratio of hysteretic loop gradient at the third cycle and a story drift of

3.50 percent to hysteretic loop gradient at the first cycle and a story drift of 0.02 percent = tan 10,24/tan 81,29 = 0.054 > 0.05.

### 7.3 Test specimen ductility

At the third cycle and a story drift of 3.50 percent, that is the yielding limit condition, under pushing load, $\delta_y$ equals to 83.94 mm. At the first cycle and a drift ratio of 0.75 percent, $\delta_i$ = 18.04 mm. The ductility, $\mu = \delta_y/\delta_i$ = 83.94/18.04 = 4.65 > 4.0. Under pulling load, $\delta_y$ equals to 83.68 mm, and $\delta_i$ equals to 17.96 mm. The ductility $\mu = \delta_y/\delta_i$ = 83.68/17.96 = 4.66 > 4.0.

## 8. CONCLUSIONS

In overall, the exterior beam-column joint meet all the requirements. To satisfy the structural stability requirements due to the lateral cyclic loading, it is recommended to increase the compression reinforcement area ($A_s'$) at the support of the beam or near the beam-column joint.

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